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Energy Systems Associates



Energy Systems Associates A CORPORATION

**THERMAL DeNO_x OPTIMIZATION
STUDY AT THE COMMERCE
REFUSE-TO-ENERGY FACILITY**

VOLUME I: TECHNICAL REPORT AND APPENDIX A

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JUNE 1988

ESR 20528-558

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SECTION 1.0

INTRODUCTION

Energy Systems Associates (ESA) was contracted by the County Sanitation Districts of Los Angeles County to perform a Thermal DeNO_x optimization study at the Commerce Refuse-to-Energy Facility located in Commerce, California. The tests were required by Permit Condition No. 31 of the Permit to Construct for the Commerce facility (Application No. 103650, granted June 5, 1985).

The objective of the test program was to evaluate Thermal DeNO_x system operating parameters (injection level, NH₃ injection rate, and carrier air pressure) in order to optimize DeNO_x operation in terms of NO_x emissions, NH₃ breakthrough, and NH₃ consumption. Testing was performed from June 14 through 17, 1988, immediately following the combustion optimization program (reported separately in ESR 20528-557).

This report presents the results and conclusions of the study. Section 2.0 contains a description of the unit, with an emphasis on the Thermal DeNO_x system. A description of the test program is contained in Section 3.0. This section includes the test matrix as well as a description of the test procedures. The results are presented in Section 4.0 and the program conclusions are presented in Section 5.0.

Appendix A, included in this volume, presents a more detailed description of the test procedures. A separate data volume contains test data, unit operating data, and quality assurance information.

SECTION 2.0
UNIT DESCRIPTION

The Commerce Refuse-to-Energy Facility consists of a municipal solid waste (MSW) fired boiler with a nominal charging rate of 320 to 380 tons per day of refuse and a steam flow rate of 115,000 lb/hr. The steam is used to generate 10 MW net (11.4 MW gross) of electricity for sale to Southern California Edison. A schematic of the system is shown in Figure 2-1.

2.1 PLANT DESCRIPTION

Air pollutant control is achieved by a number of techniques. NO_x emissions are controlled by NH_3 injection into the furnace exit gas (Exxon Thermal De NO_x). This system is described in further detail in Section 2.2. Acid gas (SO_2 and HCl) control is achieved by a Teller/AAF spray dryer, which utilizes lime to collect the acid gases. Particulate control is by an American Air Filter baghouse.

The facility is base loaded, so its design operation is full capacity 24 hrs per day.

During the testing period, the boiler was charged with the normal refuse received at the facility. This refuse is from the city of Commerce and is predominantly from commercial accounts. The boiler design criteria is presented in Table 2-1.

TABLE 2-1. BOILER DESIGN PARAMETERS

Steam Flow	115,000 lb/hr
Steam Temperature	750°F
Steam Pressure	650 psig
Refuse Feed Rate	320 to 380 TPD
Economizer Exit Temperature	460°F
Feed Water Temperature	360°F

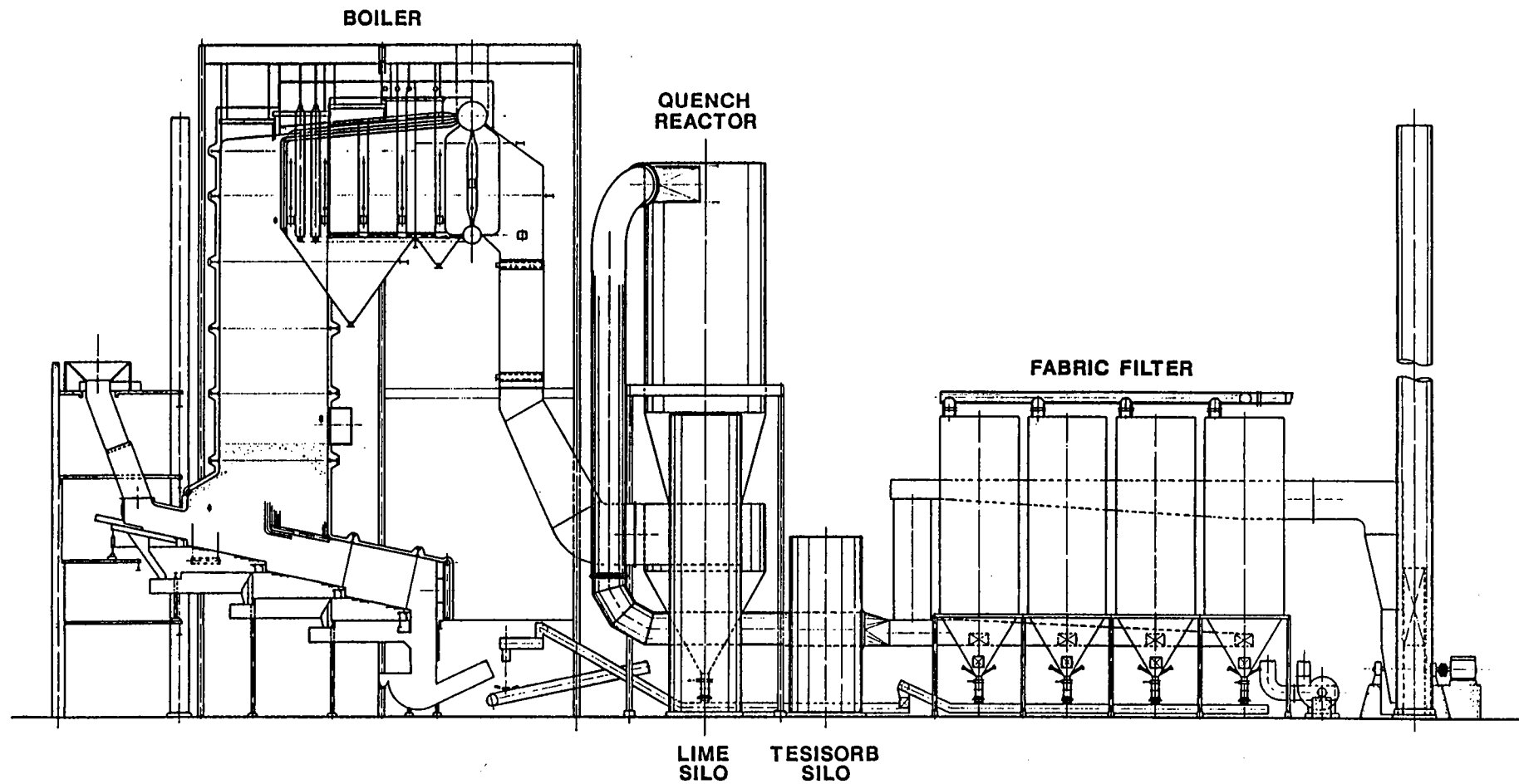
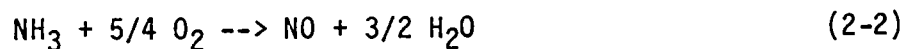
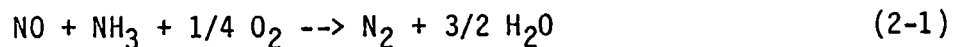


Figure 2-1. Commerce Refuse-to-Energy Facility boiler and APC equipment.

2.2 THERMAL DeNO_x SYSTEM

The Thermal DeNO_x technology (U.S. Patent No. 3,900,544) utilizes ammonia (NH₃) to react with the oxides of nitrogen in the combustion gas, forming nitrogen and water. The desired reaction occurs in the temperature range from 1600°F to 1800°F, with an optimum temperature of about 1750°F. It is a homogeneous, gas-phase reaction and, therefore, no catalyst is required. The reactions proceed in the presence of excess oxygen within a critical temperature range. The overall NO_x reduction and production reactions are summarized in Equations 2-1 and 2-2, respectively.



In typical flue gas environments, the NO reduction shown as Equation 2-1 dominates at temperatures around 1750°F. At higher temperatures, the NO production reaction shown as Equation 2-2 becomes significant, and above 2000°F the injection of NH₃ is counterproductive, causing increased NO. As temperatures are reduced below 1600°F, both reactions become extremely slow. In this case, the NO reduction falls off drastically, and a proportionally larger amount of the NH₃ flows through unreacted. Unreacted NH₃ exiting the boiler is referred to as "ammonia slip."

The Thermal DeNO_x system at Commerce consists of the following components:

1. A pressurized ammonia storage tank to both store NH₃ and provide pressure for NH₃ transport.
2. An air compressor to provide pressurized carrier air to help transport NH₃ to the boiler and provide jet penetration velocity at the injection nozzles.

3. Two rows of injection nozzles located on each sidewall of the upper furnace. The two elevations are referred to as the top and bottom elevations, and one elevation is used at a time.

NH₃ flow rate can be controlled automatically or manually from the control room. Air compressor output and injection elevation selection are controlled manually at the equipment location.

SECTION 3.0

TEST PROGRAM

The test program was conducted in accordance with a test plan outlined in a letter dated January 23, 1987, from Michael Selna of the Commerce Refuse-to-Energy Authority to Emmanuel Ruivivar of the SCAQMD. The plan was approved, with certain conditions, by the SCAQMD in a letter dated April 1, 1987. The test plan and the SCAQMD response both specified test conditions and sampling procedures to be used. These conditions were followed, and are described below.

3.1 TEST CONDITIONS

The test matrix is presented in Table 3-1. Thirty-two data points were collected at a total of nineteen different operating conditions.

The original test matrix called for twelve test conditions: two injection levels (top and bottom) by two air compressor outlet pressures (20 and 30 psig) by three stoichiometric mole ratios (1, 2, and 3). Since results of the early tests showed no significant difference in DeNO_x performance between air pressures of 20 and 30 psi, extra tests were added to the test matrix at four lower air compressor settings (8, 2, 1, and 0 psig) in order to evaluate DeNO_x performance over the full compressor operating range.

A single test, Test 40, was excluded from the data base used for reporting of results because it was collected during a load transient condition and indicated NO_x removal efficiency was only 2%. A total of four exploratory tests were performed outside the test matrix at 85 and 95% load, and at 60 lb/hr NH_3 injection rate. These tests are not included in the test matrix, but the data are available in the data volume.

All tests were performed at nominal boiler operating conditions of 7.0 to 7.5% furnace O_2 set point, and overfire air in manual control at 70 to 80 klb/hr (approximately 40% ofa). Frequent checks of the composition of the

TABLE 3-1. TEST MATRIX FOR THERMAL DeNO_x OPTIMIZATION PHASE
Numbers in table indicate test numbers

	NH ₃ Injection Rate, lb/hr		
	15	30	45
Top row, 30 psi air	24,36	22,34,45,52	19,31,44,46
Top row, 20 psi air	23,35	21,33	20,32
Top row, 8 psi air			39,41,42
Top row, 2 psi air		47,50	48
Top row, 1 psi air		51	
Top row, compressor off	55	53	54
Bottom row, 30 psi air	27	26	25
Bottom row, 30 psi air	30	29	28

refuse being fed to the boiler were made by visual observation and by conversations with the crane operators. There was some variation in the composition of the fuel mix being fed to the boiler, but the variation was well within the normal bounds of operation.

Even at fixed boiler control set points, variations in the fuel side resulted in a high variability in baseline NO_x levels. Baseline NO_x values ranged from 165 to 281 ppmc (ppmc indicates parts per million by volume, corrected to 3% O_2), with a mean of 208 ppmc and a standard deviation of 31 ppmc. This variation impacted the selection and attainment of stoichiometric mole ratios, and the determination of baseline NO_x values used to quantify NO_x reductions.

Target stoichiometric mole ratios for the tests were 1, 2, and 3 moles NH_3 /mole NO_x . Since the variability in NO_x made it difficult to establish a mole ratio for any test, it was decided to use fixed NH_3 mass flow rates for test set points.

Based on an average NO_x mass emission rate of approximately 40 lb/hr, NH_3 rate of 15, 30 and 45 lb/hr were selected to correspond to mole ratios of 1, 2, and 3.

Determination of baseline NO_x values was difficult due to fluctuations in NO_x with time. In order to best quantify NO_x reductions at each test condition, the following sequence was used for each test:

1. Collect baseline data with NH_3 off for 5-10 minutes
2. Test with NH_3 on for 20 minutes
3. Collect post-test baseline for 5-10 minutes

The average of the pre- and post-test baseline values was used as the baseline for each test. Stoichiometric mole ratios were calculated using the baseline NO_x concentration, the NH_3 mass rate, and an average stack mass flow rate value.

3.2 TEST PROCEDURES

Test procedures for this program included:

1. Continuous gaseous measurement at the stack of NO_x , O_2 , and CO
2. Extractive wet chemical tests at selected test points at the boiler exit and at the stack for NH_3
3. Stack plume observations
4. Collection of unit data and monitoring of unit operation

3.2.1 Gaseous Emissions

Gaseous emissions (NO_x , CO, and O_2) at the stack were measured using ESA's continuous emissions monitor (CEM) described in Appendix A. A heated Teflon line and supercooled ice bath were used to prevent loss of NO_2 in the sampling system. Single point gaseous sampling was performed since earlier tests had shown no significant stratification of gaseous species.

The type of instruments, range, and outputs used are listed in Table 3-2. CO was measured using two analyzers: a Teco analyzer with very low range capability and no CO_2 interference, and a Horiba analyzer with a lower range of 0-1000 ppm and slight CO_2 interference (approximately 1 ppm CO per % CO_2 , or 8-10 ppm CO for these tests). The Teco analyzer was used as the primary instrument. During the tests, there were instances where CO values momentarily exceeded the 0-200 ppm range set for the Teco. In these cases, data from the Horiba analyzer was used. Comparison of the results from the two analyzers showed excellent agreement (within 3 ppm CO after correction for CO_2 interference). The Teco analyzer was not available after the first day of testing, so the Horiba analyzer only was used for the last three days.

Instrument calibrations were performed at regular intervals and system bias tests were performed once or twice per day. All calibration drift and system bias data were within EPA and SCAQMD specifications.

The sampling system bias was also checked using a gas containing approximately 25 ppm NO_2 and the loss in NO_x was less than 1% of scale, thus verifying that any NO_2 that might be present in the sample gas would be

conserved. However, no detectable NO₂ was measured during any of the eleven times that NO vs. NO_x measurements were checked.

TABLE 3-2
GASEOUS INSTRUMENTS USED FOR
COMMERCE COMBUSTION OPTIMIZATION PROGRAM

Species	Instrument Mfr.	Scale	Output to:	
			Strip Chart	Data Logger
NO _x	Teco	0-250 ppm	X	X
CO	Teco	0-200 ppm	X	X
O ₂	Teledyne	0-25%	X	X
CO	Horiba	0-1000 ppm		X
CO ₂	Horiba	0-25%		X

Data from the instruments was recorded using a Metrosonics d721 data logger. Instrument readings were taken at a frequency of once per second and combined into 2-minute averages. At the end of each test or day, the data was stored on a diskette for later computer retrieval.

3.2.2 Ammonia Sampling

NH₃ slip measurements were made at the boiler exit and stack for selected test conditions. Samples were obtained by extracting a sample, filtering it through a heated filter, and bubbling the gas through impingers containing dilute sulfuric acid. NH₃ is collected in the impingers and analyzed using an ion specific electrode.

Standard information on the sampling and analysis is included in Appendix A. Additional details specific to this program are presented below.

Sample Location. Since NH₃ is a gaseous species, samples were collected nonisokinetically at approximately the center point of each sample duct.

Filter Temperature. Since NH_3 can react with HCl to form ammonium chloride, and since there are high levels of HCl present in the boiler exit gas, maintenance of proper filter temperature is important to ensure that gaseous NH_3 does not form solid NH_4Cl upstream of the filter in the sample train.

At the boiler exit, this was accomplished by using an in-stack EPA Method 17-type filter. Use of an in-stack filter allows segregation of gaseous NH_3 from any potential ammonium salts at exhaust gas temperatures. Any ammonium salts formed in the sample train downstream of the filter are collected by water washing of the probe and are measured as NH_3 .

At the stack sample was extracted using a heated probe and filtered through a Method 5 filter maintained at 300°F , the approximate stack temperature.

3.2.3 Stack Opacity Observations

The SCAQMD variance which allowed collection of test data without the Thermal De NO_x system in service specified that visible observations of the stack plume must be made, and that if a visible ammonium chloride plume were present, the NH_3 feed rate must be immediately reduced to alleviate the plume.

Visible observations of the stack were made during each test, and no visible plume was detected at any of the test conditions.

3.2.4 Unit Operation

During each test, data for a wide variety of unit operating parameters was collected using plant instrumentation. Key parameters such as unit load, UGA and OFA flow, and furnace O_2 were recorded on a 15-minute average basis. Graphs of parameters such as NH_3 flow, furnace O_2 , NO_x emissions, load, etc. were also obtained for each test using the control room computer system. Unit operating data is included in Appendix D (in Volume II).

SECTION 4.0

RESULTS

This section presents the results of the Thermal DeNO_x optimization tests. The general results of the program are presented, followed by discussions of the three test variables (injection location, carrier air flow, and NH₃ rate) and NH₃ slip.

4.1 GENERAL RESULTS

The results of the tests are presented in Tables 4-1 through 4-3. Table 4-1 presents the results of the tests using the top injection row, Table 4-2 presents the results of the tests using the bottom injection row, and Table 4-3 presents a summary of the NO_x reductions achieved by NH₃ injection.

Discussions and graphs of the data are presented in the following sections.

4.2 IMPACT OF INJECTION LOCATION

Table 4-3 presents a comparison of average reductions achieved using the top and bottom injection rows. The results show that significantly better results were achieved using the top row.

A comparison of top vs. bottom row effectiveness was made after the first twelve tests of the program, and the conclusion was made at that time that use of the top row of nozzles was more effective. As a result, all subsequent tests to evaluate carrier air flow, NH₃ rate, and data repeatability were performed using the top injection row only.

4.3 IMPACT OF CARRIER AIR FLOW

Carrier air is used in the Thermal DeNO_x system to assist in carrying NH₃ from the NH₃ storage tank to the boiler, and to provide increased volumetric flow and thus increased jet velocities at the injection nozzles.

TABLE 4-1. RESULTS OF THERMAL DeNO_x EVALUATION TESTS - TOP INJECTION ROW

Test No.	Injection Level	NH ₃ Rate, lb/hr	Mole Ratio, mole NH ₃ /mole NO _x	Carrier air flow scfm	Carrier air pressure psig	Stack O ₂ , %	Baseline NO _x , ppm @ 3% O ₂	NO _x , ppm @ 3% O ₂	% NO _x Reduction
55	Top	15	0.68	120	0	10.6	256	187	27.0
23	Top	15	0.95	730	20	9.8	184	135	26.4
36	Top	15	0.86	740	20	9.6	173	138	20.2
24	Top	15	0.92	800	30	9.8	186	159	14.5
35	Top	15	0.82	880	30	9.1	177	136	23.2
53	Top	30	1.43	120	0	10.4	240	135	43.8
51	Top	30	1.32	140	1	10.0	236	138	41.5
47	Top	30	1.38	310	2	10.2	245	137	44.1
50	Top	30	1.57	320	2	10.2	205	87	57.5
21	Top	30	1.98	730	20	10.6	165	81	50.9
33	Top	30	1.73	750	20	10.5	193	105	45.6
22	Top	30	1.74	800	30	10.4	187	96	48.7
52	Top	30	1.27	850	30	9.0	201	132	34.3
45	Top	30	1.18	850	30	10.3	281	138	50.9
34	Top	30	1.70	870	30	9.0	176	137	21.9
54	Top	45	2.06	120	0	10.7	246	126	48.8
47	Top	45	2.14	310	2	9.9	221	111	49.8
41	Top	45	2.27	530	8	9.5	212	152	28.3
42	Top	45	2.35	530	8	10.2	216	135	37.5
39	Top	45	2.70	530	8	9.4	178	146	18.0
20	Top	45	2.85	730	20	10.5	182	83	54.4
32	Top	45	2.44	750	20	10.5	213	108	49.3
19	Top	45	2.55	800	30	8.9	192	75	60.9
46	Top	45	2.09	810	30	10.3	242	190	21.3
31	Top	45	2.71	850	30	10.7	195	90	53.8
44	Top	45	1.79	880	30	10.3	269	102	62.0

TABLE 4-2. RESULTS OF THERMAL DeNO_x EVALUATION TESTS - BOTTOM INJECTION ROW

Test No.	Injection Level	NH ₃ Rate, lb/hr	Mole Ratio, mole NH ₃ /mole NO _x	Carrier air flow scfm	Carrier air pressure psig	Stack O ₂ , %	Baseline NO _x , ppm @ 3% O ₂	NO _x , ppm @ 3% O ₂	% NO _x Reduction
30	Bottom	15	0.85	680	20	9.9	200	175	12.5
27	Bottom	15	0.92	710	30	9.4	169	150	11.0
29	Bottom	30	1.99	670	20	10.7	213	161	24.4
26	Bottom	30	1.77	710	30	8.9	174	147	15.3
28	Bottom	45	2.26	670	20	10.5	215	138	35.7
25	Bottom	45	2.46	730	30	10.6	200	103	48.4

TABLE 4-3. SUMMARY OF NO_x REDUCTIONS

Injection Location	NH ₃ rate, lb/hr	Average Mole Ratio NH ₃ /NO _x	No. Tests	NO _x Reduction, %			
				Avg.	High	Low	S.D.*
Top Row	15	0.85	5	22.3	27.0	14.5	5.1
	30	1.53	10	43.9	57.5	21.9	9.9
	45	2.36	11	44.0	62.0	18.0	15.4
Bottom Row	15	0.89	2	11.8	12.5	11.0	1.1
	30	1.88	2	19.9	24.4	15.3	6.4
	45	2.36	2	42.1	48.4	35.7	9.0

* S.D. - standard deviation

Increased jet velocities are intended to improve penetration and mixing of NH_3 with the furnace exhaust gases.

The original test matrix called for evaluation of air compressor outlet pressures of 20 and 30 psig. Maximum achievable pressure was actually 27 to 30 psi. After duplicate tests using these two air pressures at three different NH_3 flow rates each, two conclusions were made:

1. There was no consistent difference in Thermal DeNO_x system performance between the two air pressures, and
2. The range of carrier air flows achieved by varying air pressure was small.

For those two reasons, it was decided to run a number of tests at reduced air pressures to determine if there was a threshold or minimum air flow level required in order to achieve significant NO_x reductions. A number of tests were run at reduced pressures of 8, 2, 1, and 0 psig, with 0 psig representing no carrier air flow at all.

The results are illustrated in Figure 4-1, and summarized in Table 4-4. The results show that Thermal DeNO_x system efficiency was essentially unaffected by carrier air flow and pressure, even to the point of completely shutting off air flow.

Conclusions. These results leads to the following conclusions:

1. Mixing of NH_3 and furnace gas is adequate for high NO_x reduction efficiency at low or nonexistent carrier air flows.
2. For the purposes of this test program, carrier air flow is not a test variable that needs to be considered when evaluating the impact of other parameters on system performance.

NOx Reduction vs Carrier Air Rate

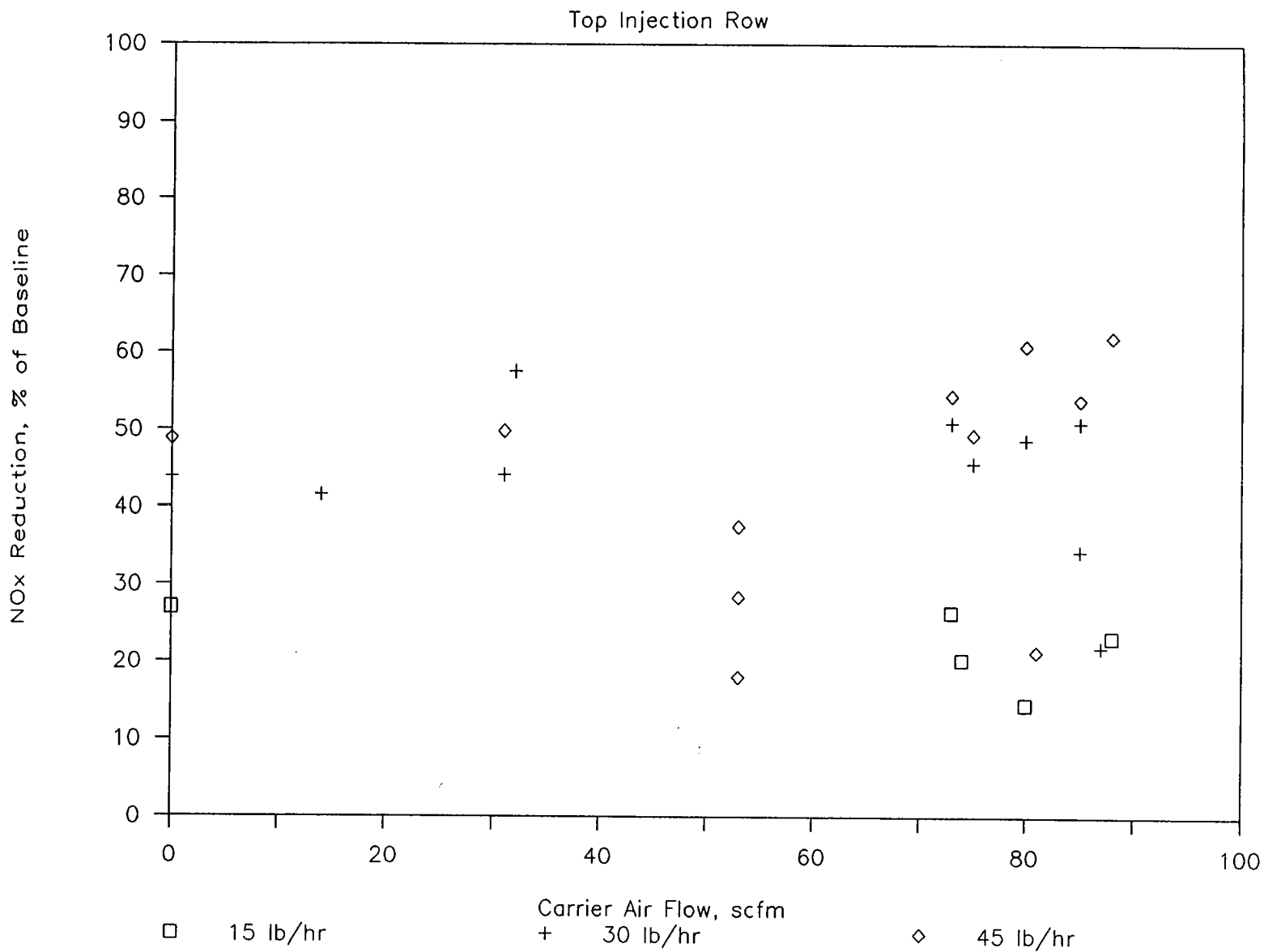


Figure 4-1. NOx reduction vs. Carrier Air flow, top injection row.

TABLE 4-4. SUMMARY OF IMPACT OF CARRIER AIR PRESSURE ON NOx REDUCTIONS

Injection Location	NH ₃ rate, lb/hr	Carrier Air Pressure	No. Tests	NOx Reduction, %		
				Avg.	High	Low
Top	15	0	1	27.0	-	-
Top	15	20	2	23.3	26.4	20.2
Top	15	30	2	18.9	23.2	14.5
Top	30	0	1	43.8	-	-
Top	30	1	1	41.5	-	-
Top	30	2	2	50.8	57.5	44.1
Top	30	20	2	48.3	50.9	45.6
Top	30	30	4	39.0	50.9	21.9
Top	45	0	1	48.8	-	-
Top	45	2	1	49.8	-	-
Top	45	8	3	27.9	37.5	18.0
Top	45	20	2	51.9	54.4	49.3
Top	45	30	4	49.5	60.9	21.3
Bottom	15	20	1	12.5	-	-
Bottom	15	30	1	11.0	-	-
Bottom	30	20	1	24.4	-	-
Bottom	30	30	1	15.3	-	-
Bottom	45	20	1	35.7	-	-
Bottom	45	30	1	48.4	-	-

4.4 IMPACT OF NH₃ INJECTION RATE

The impact of NH₃ injection rate on NO_x emissions is shown in Figures 4-2 through 4-5. Figures 4-2 and 4-3 show NO_x reductions (in percent of baseline) plotted against stoichiometric mole ratio for the top and bottom rows, and Figures 4-4 and 4-5 show NO_x concentration plotted against NH₃ rate for the two locations. Table 4-3 summarized the reductions achieved at each injection level and NH₃ mass rate combination.

A review of the data leads to the following observations.

1. Data Scatter. There is a high degree of scatter in the data, due to the variable nature of the combustion process on a refuse-fired boiler. Figures 4-4 and 4-5 show the level of scatter in baseline NO_x concentrations, and in NO_x levels with NH₃ injection on. The variability is reduced somewhat by plotting NO_x percentage reduction vs. stoichiometric mole ratio in Figures 4-2 and 4-3, but there still remains a great deal of scatter.

The scatter in baseline NO_x levels is due primarily to essentially uncontrollable combustion variables such as fuel composition, fuel bed depth, fuel/air mixing, etc. Additional scatter in the NO_x reduction data is probably due to temporal and spatial variations in such items as gas temperature and gas velocity, and possibly to variations in gas composition. These factors all vary significantly within the normal range of steady, full load operation.

Thus, although average NO_x reductions of 44% were achieved at the best operating conditions top row, 30 and 40 lb NH₃/hr, there were individual tests at these conditions where reductions as low as 18% or as high as 62% were seen. A review of the data in an attempt to correlate NO_x reductions with other factors such as baseline NO_x concentration or gas temperatures did not reveal any correlation or explanation for the scatter.

2. Effect of NH₃ rate. The figures and the table show that for the top row, NO_x removal efficiency increases sharply with NH₃ injection rate at low rates, and then levels off at a mole ratio of 1.6 to 2.0. For the bottom row, where removal efficiencies are lower, NO_x reductions continue to increase at mole ratio up to 2.5. However, removal efficiencies with the bottom row at

NOx Reduction vs. NH₃/NO Mole Ratio

Top Injection Row

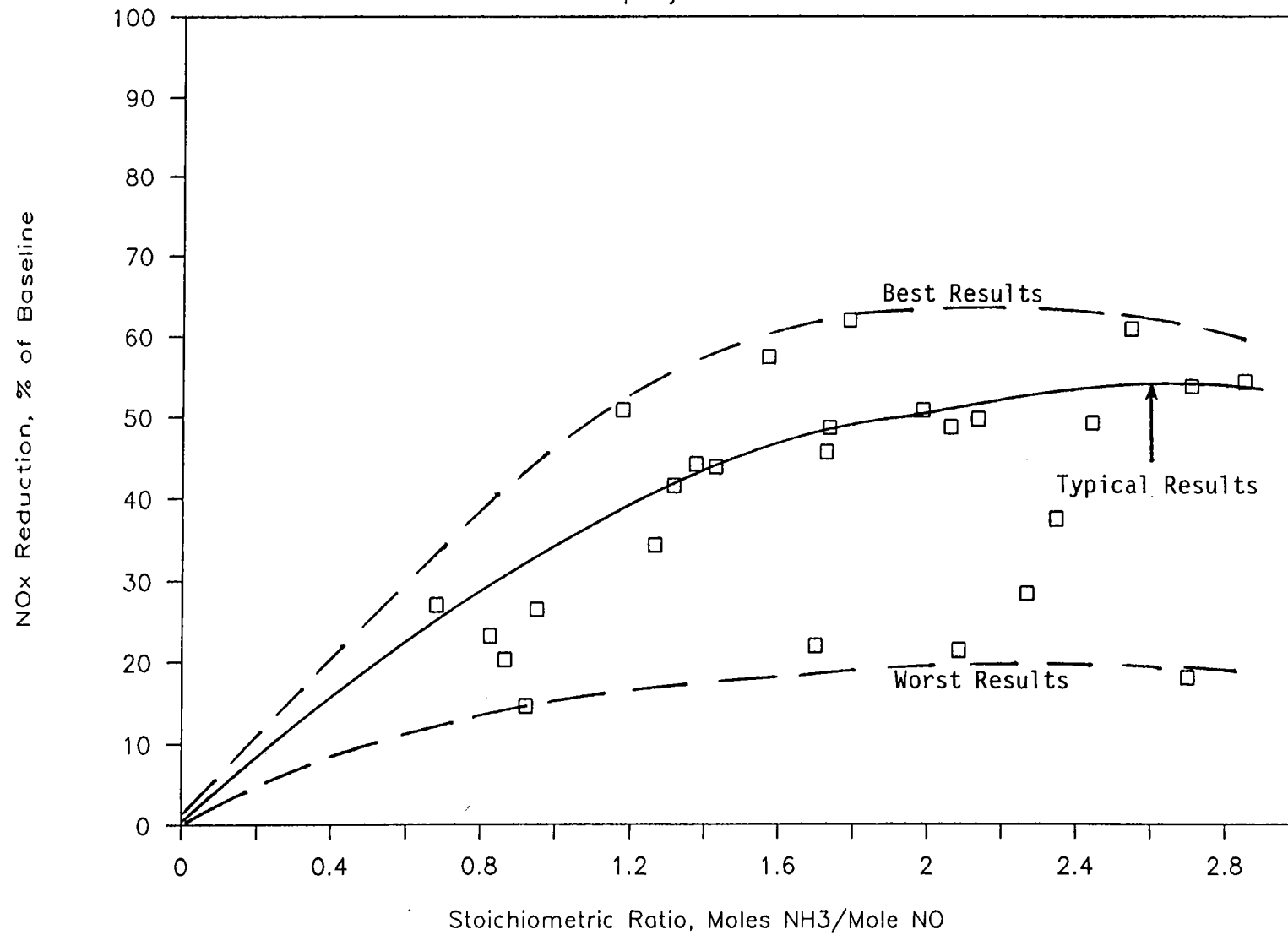


Figure 4-2. NOx reduction vs. NH₃/NO mole ratio.

NOx Reduction vs. NH3/NO Mole Ratio

Bottom Injection Row

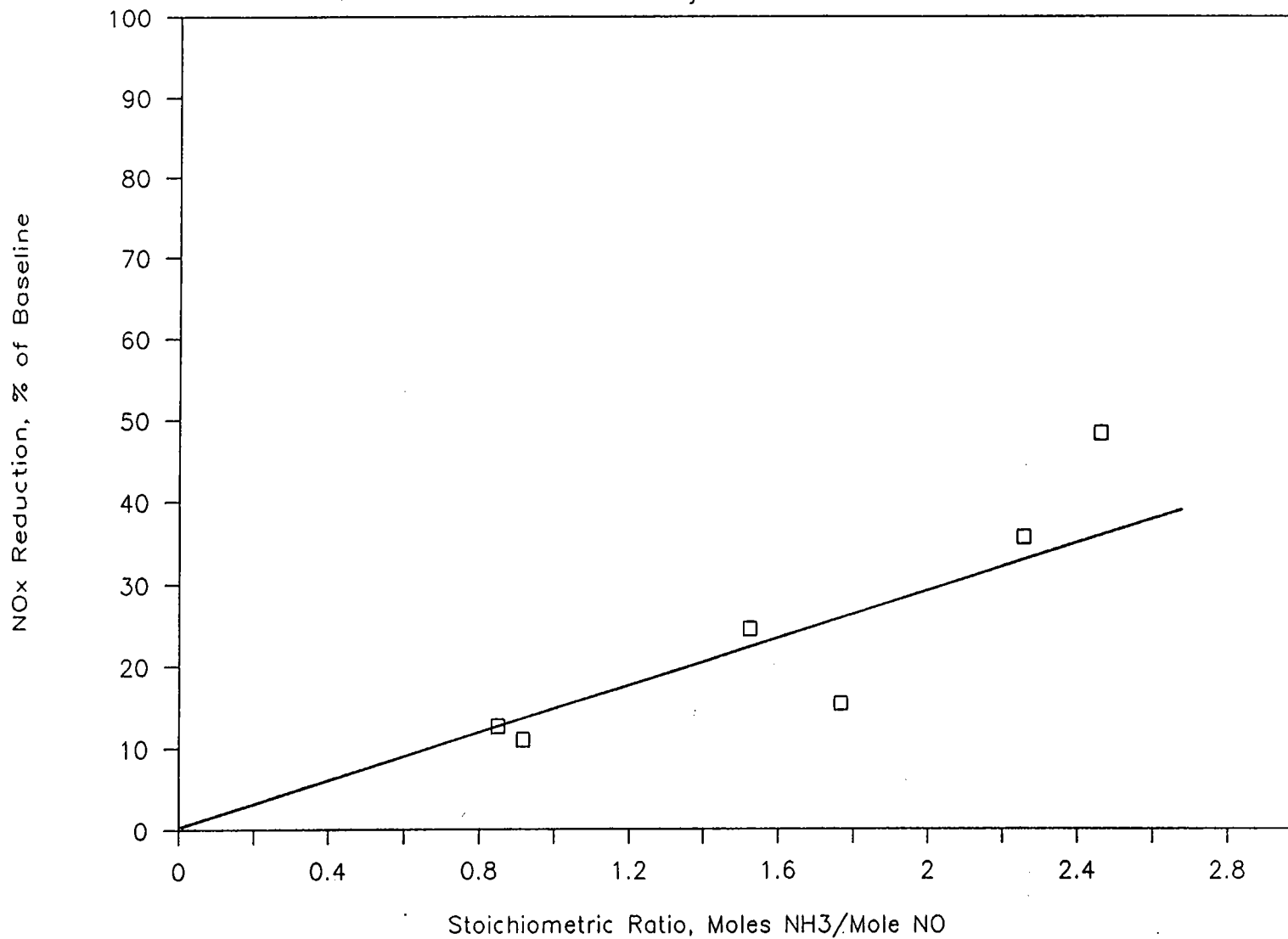


Figure 4-3. NOx reduction vs. NH3/NO mole ratio.

NOx Concentration vs. NH₃/NO Mole Ratio

Top Injection Row

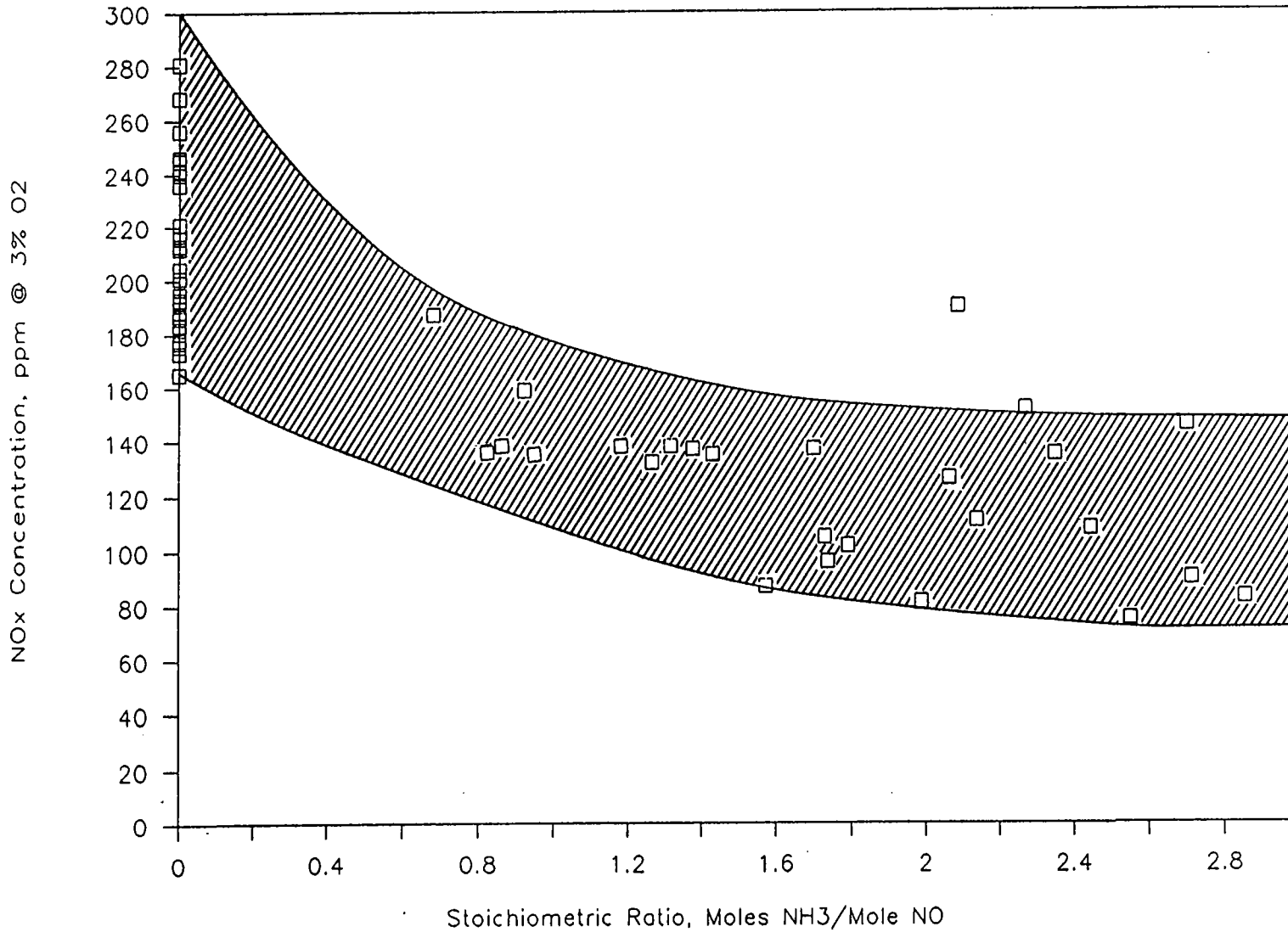


Figure 4-4. NOx concentration vs. NH₃/NO mole ratio.

NOx vs NH3 Rate

Bottom Injection Row

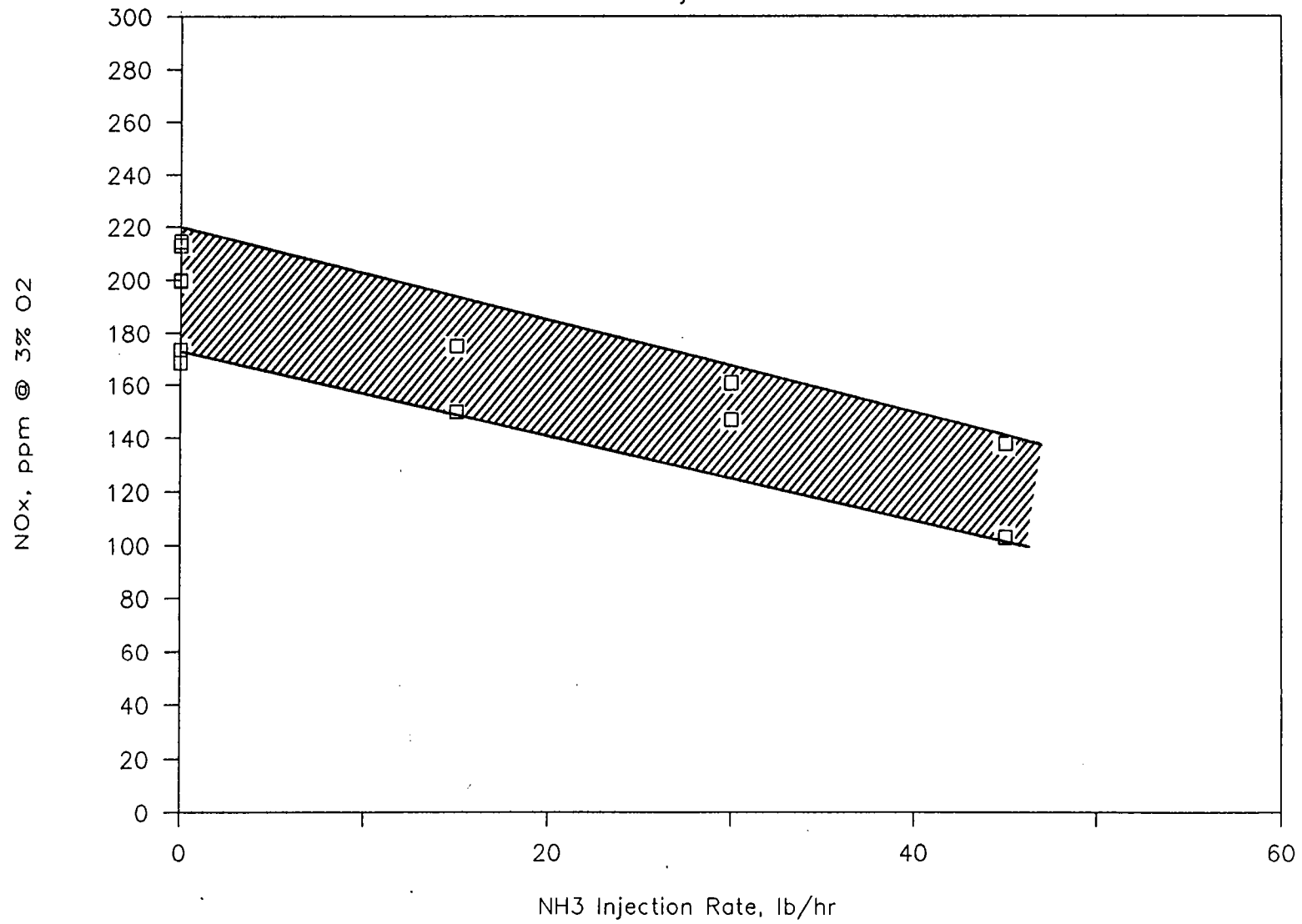


Figure 4-5. NOx concentration vs. NH₃ injection rate, bottom injection row.

high NH_3 rates are still lower than removal efficiencies with the top row at lower NH_3 rates.

Conclusion. The conclusion to be drawn from the data is that the best NO_x reductions can be achieved by using the top injection row at an injection rate of 30 lb/hr NH_3 (NH_3/NO mole ratio of 1.5). Increasing the NH_3 injection rate to 45 lb/hr does not improve system performance.

4.5 NH_3 EMISSIONS

The results of the NH_3 slip measurements are presented in Table 4-5 and in Figure 4-6. Eight tests were performed at four different NH_3 injection rates: 0, 15, 30, and 45 lb/hr. Stack measurements were made for six of the tests, and boiler exit measurements were made for all eight tests.

The data show that NH_3 levels at the stack were negligible (<2 ppmc) for all NH_3 injection test conditions. In fact, stack NH_3 levels with NH_3 injection in service were lower than the baseline level of 3.4 ppmc. This indicates that the spray drier/baghouse system removes essentially all NH_3 exiting the boiler.

For the first group of tests (Tests 19, 27, and 24), NH_3 slip at the boiler exit increased significantly with NH_3 injection rate. However, for the second group of tests boiler exit NH_3 levels were negligible for all but one test.

The major difference between the two groups of tests is that during the first group of tests NO_x removal efficiency was relatively high, while during the second group of tests NO_x removal was much lower.

A clearer trend is seen if NH_3 slip is plotted against NO_x removal efficiency as in Figure 4-7. The figure shows a clear trend of NH_3 slip increasing with NO_x removal efficiency. NH_3 slip is normally a function of injection temperature. At temperatures above 1800°F there is usually very little NH_3 slip, while NH_3 slip increases sharply as temperatures drop below 1750°F. This data indicates, then, that the system at Commerce may be more efficient in controlling NO_x during low temperature excursions than during high temperature excursions.

TABLE 4-5. NH₃ SLIP MEASUREMENTS

Test No.	NH ₃ rate, lb/hr	NH ₃ /NO mole ratio	NO _x reduction, %	NH ₃ ppm @ 3% O ₂	
				Boiler exit	Stack
16/17	0	0	0	1.9	3.4
19	45	2.55	61	52.7	1.6
22	30	1.74	49	26.1	0.8
24	15	0.90	15	2.2	0.8
34	30	1.70	22	0.6	--
35	15	0.82	23	0.2	--
39	45	2.70	18	1.9	1.5
41	45	2.27	28	10.2	1.2

NOTE: All tests performed using top row of injection nozzles

NH3 Slip vs NH3/NO Mole Ratio

Top Injection Row

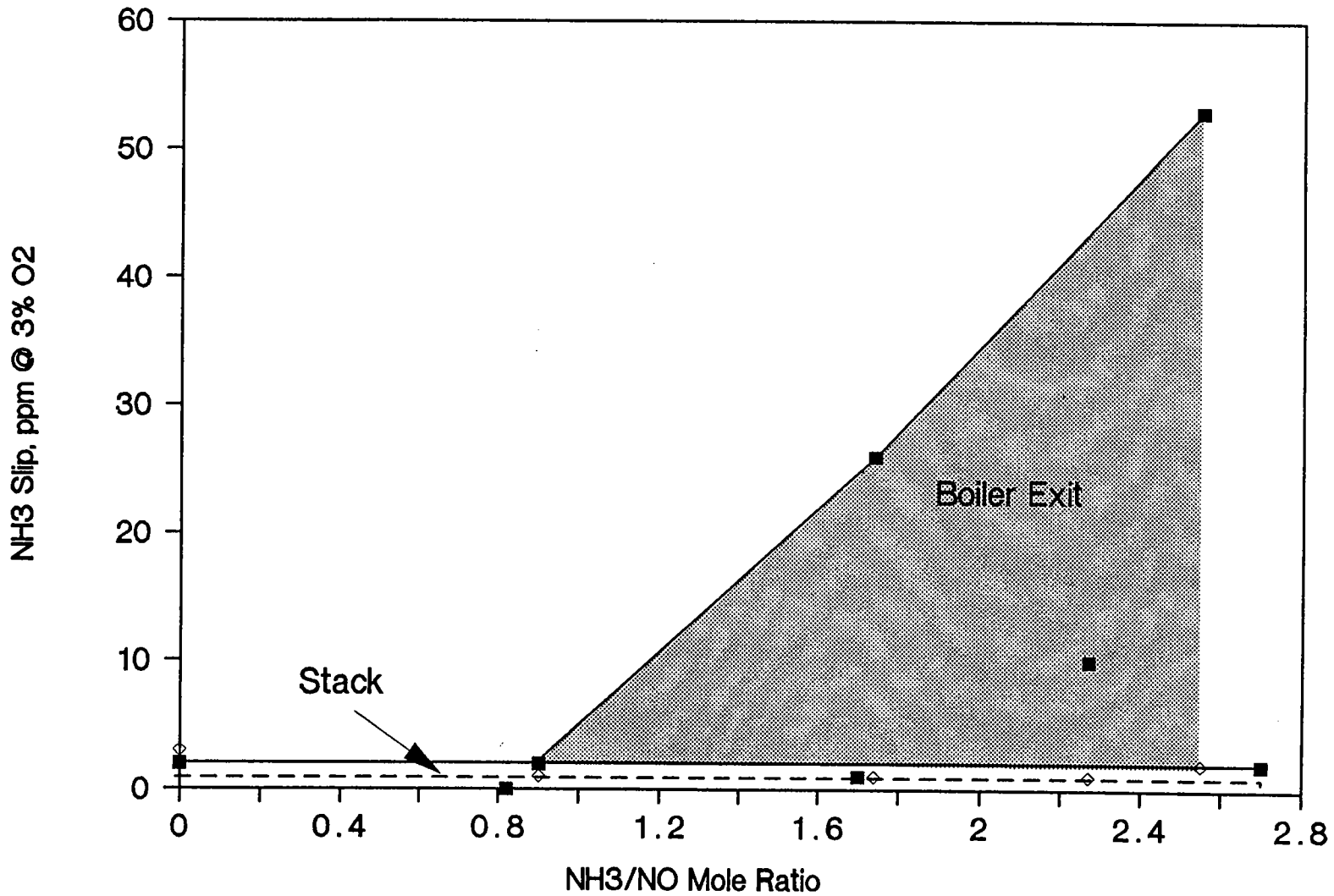


Figure 4-6. NH3 Slip vs. NH3/NO Mole Ratio.

NH3 Slip vs NOx Removal Efficiency

Top Injection Row

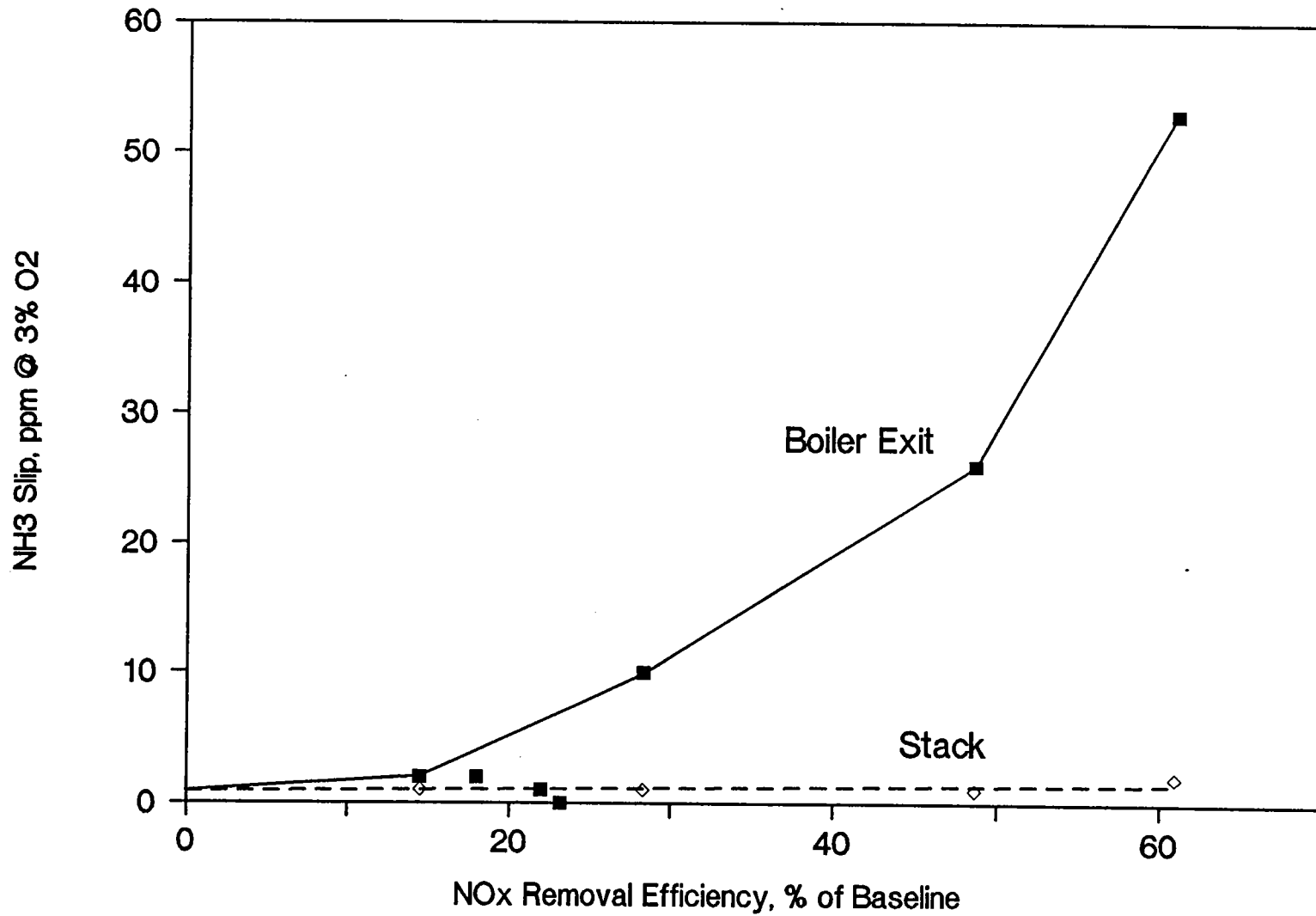


Figure 4-7. NH3 Slip vs. NOx Removal Efficiency

SECTION 5.0

CONCLUSIONS

Based on the results obtained during the Thermal DeNO_x optimization program, the following conclusions are drawn:

1. Optimum operation of the Thermal DeNO_x system is with injection through the top row of nozzles, with NH₃ flow set at 30 lb/hr or greater (mole ratio of 1.5 or greater).
2. Carrier air flow rate had no effect on DeNO_x system performance.
3. Although average NO_x reductions of 44% could be achieved at optimum conditions, there were numerous tests at these conditions where reductions as low as 20% were seen.
4. The spray dryer scrubber system removed essentially all the ammonia exiting the boiler so that NH₃ slip at the stack was negligible for all test conditions. There was no visible ammonium chloride plume throughout the program.

APPENDIX A
MEASUREMENT PROCEDURES

Continuous Emissions Monitoring System
Oxygen (O₂) by Continuous Analyzer
NO/NO_x by Continuous Analyzer
Carbon Monoxide (CO) by Continuous Analyzer
Ammonia

Continuous Emissions Monitoring System

O₂, CO, CO₂, NO, NO_x, and SO₂ are measured using an extractive continuous emissions monitoring (CEM) package, shown in the following figure. This package is comprised of three basic subsystems. They are: (1) the sample acquisition and conditioning system, (2) the calibration gas system, and (3) the analyzers themselves. This section presents a description of the sampling and calibration systems. Descriptions of the analyzers used in this program and the corresponding reference test methods follow. Information regarding quality assurance information on the system, including calibration routines and system performance data follows.

The sample acquisition and conditioning system contains components to extract a representative sample from the stack or flue, transport the sample to the analyzers, and remove moisture and particulate material from the sample. In addition to performing the tasks above, the system must preserve the measured species and deliver the sample for analysis intact. The sample acquisition system extracts the sample through a stainless steel probe. The probe is insulated or heated as necessary to avoid condensation. If the particulate loading in the stack is high, a sintered stainless steel filter is used on the end of the probe.

Where water soluble NO₂ and/or SO₂ are to be measured, the sample is drawn from the probe through a heated Teflon sample line into a supercooled (approximately -20 °C) water removal trap. The trap consists of stainless steel flasks in a bath of dry ice and antifreeze. If dry ice is not locally available, ice and rock salt are used. This design removes the water vapor by condensation and freezes the liquid quickly. The contact between the sample and liquid water is minimized. Since the solubility of the NO₂ and SO₂ in ice is negligible, these species are conserved. This system meets the requirements of EPA Method 20. The sample is then drawn through a Teflon transport line and particulate filter, into the sample pump. The pump is a dual head, diaphragm pump. All sample-wetted components of the pump are stainless steel or Teflon. The pressurized sample leaving the pump flows through a stainless steel refrigerated (38 °F) compressed air dryer for final moisture removal. A drain line and valve are provided to constantly expel any condensed moisture from the dryer. After the dryer, the sample is directed into a distribution manifold. Excess sample is vented through a back-pressure regulator, maintaining a constant pressure of 5-6 psig to the analyzers.

The calibration system is comprised of two parts: the analyzer calibration, and the system calibration check (dynamic calibration). The analyzer calibration equipment includes pressurized cylinders of certified span gas. The gases used are, as a minimum, certified to ±1% by the manufacturer where necessary, to comply with reference method requirements. EPA Protocol 1 gases are used. The cylinders are equipped with pressure regulators which supply the calibration gas to the analyzers at the same pressure and flow rate as the sample. The selection of zero, span, or sample gas directed to each analyzer is accomplished by operation of the sample/calibration selector valves.

The system calibration check is accomplished by transporting the same gases used to zero and span the analyzers to the sample conditioner inlet (probe exit). The span gas is exposed to the same elements as the sample and the system response is documented. Where the supercooled moisture removal system is used, water is added to the knockout flasks before the pre-test check. The analyzer indications for the system calibration check must agree within 3% of the analyzer calibration. Values are adjusted and changes/repairs are made to the system to compensate for any difference in analyzer readings. Specific information on the analytical equipment and test methods used is provided in the following pages.

Method: NO/NOx by Continuous Analyzer

Applicable
Ref. Methods: EPA 7E, EPA 20; ARB 1-100, BA ST-13A

Principle: A sample is continuously drawn from the flue gas stream, conditioned, and conveyed to the instrument for direct readout of NO or NOx.

Analyzer: Teco Model No. 10AR

Measurement
Principle: Chemiluminescence

Accuracy: $\pm 1\%$ of full scale

Ranges: 0-2.5, 0-10, 0-25, 0-100, 0-250, 0-1000, 0-2500, 0-10,000 ppm

Output: 0-10 mV

Inferences: Compounds containing nitrogen (other than ammonia) may cause interference.

Response
Time: 90%, 1.5 seconds (NO mode) and 1.7 seconds (NOx mode)

Sampling
Procedure: A representative flue gas sample is collected and conditioned using the CEM system described previously. If EPA Method 20 is used, that method's specific procedures for selecting sample points are used. Otherwise, the procedures described in the report are used to select sample locations.

Analytical
Procedure: The oxides of nitrogen monitoring instrument is a chemiluminescent nitric oxide analyzer. The operational basis of the instrument is the chemiluminescent reaction of NO and ozone (O_3) to form NO_2 in an excited state. Light emission results when excited NO_2 molecules revert to their ground state. The resulting chemiluminescence is monitored through an optical filter by a high sensitivity photomultiplier tube, the output of which is electronically processed so it is linearly proportional to the NO concentration. The output of the instrument is in ppmV.

Method: Carbon Monoxide (CO) by Continuous Analyzer

Applicable
Ref. Methods: EPA 10; ARB 1-100; BA ST-6

Principle: A sample is continuously drawn from the flue gas stream, conditioned, and conveyed to the instrument for direct readout of CO concentration.

Analyzer: Horiba, Model PIR 2000

Measurement
Principle: Nondispersive infrared (NDIR)

Accuracy: $\pm 1\%$ of full scale

Ranges: 0-500, 0-1500, 0-2500 ppm

Output: 0-10 mV

Interferences: Any substance (e.g., cyanogen, methyl azide, CO₂, H₂O) having a strong absorption of infrared energy will interfere to some extent.

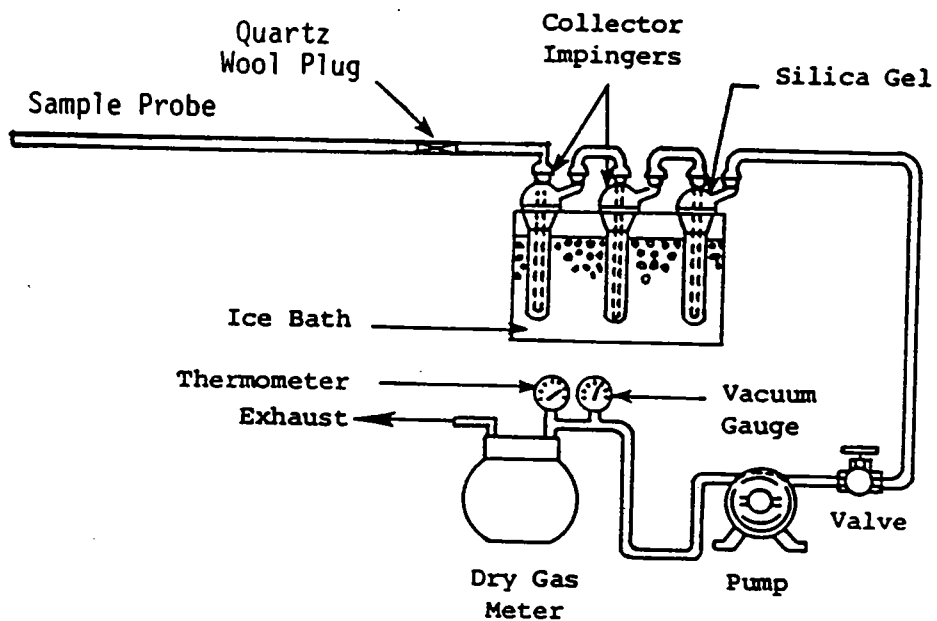
Interference by H₂O is less than 0.5 ppm based on manufacturer's interference data and moisture tests conducted at the sample conditioner outlet. CO₂ interference is up to 10 ppm, and is corrected based on measured CO₂ values and interference factors measured by ESA.

Response
Time: 1.2 seconds

Sampling
Procedure: A representative flue gas sample is collected and conditioned using the CEM system described previously. Sample point selection has been described previously.

Analytical
Procedure: Carbon monoxide concentrations are measured by short pathlength nondispersive infrared analyzers. These instruments measure the differential in infrared energy absorbed from energy beams passed through a reference cell (containing a gas selected to have minimal absorption of infrared energy in the wavelength absorbed by the gas component of interest) and a sample cell through which the sample gas flows continuously. The differential absorption appears as a reading on a scale of 0 to 100% and is then related to the concentration of the specie of interest by calibration curves supplied with the instrument.

Comparison to
Other Methods: Use of this method with the CO₂ and H₂O interference corrections has yielded results within 1% of instrument scale when compared to simultaneous tests performed using the SCAQMD TCA method.



Ammonia sampling probe/train arrangement.



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